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RESEARCH FOR INFORMATION EXTRACTION FROM AERIAL IMAGERY

BY

ROBERT D. LEIGHTY

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The U. S. Army Engineer Topographic Laboratories is investigating a number of approaches to information extraction from aerial imagery. Two approaches will be discussed in this paper: Automated feature extraction research and computer-assisted photo interpretation research. The discussion of automated information extraction indicates present day capabilities of automated systems, problems facing automated information extraction, and directions which basic research must take to achieve automated "smart analysis systems" in the distant future. The discussion of computer-assisted photo interpretation will describe the

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RESEARCH FOR INFORMATION EXTRACTION FROM AERIAL IMAGERY

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ABSTRACT

The U. S. Army Engineer Topographic Laboratories is investigating a number of approaches to information extraction from aerial imagery. Two approaches will be discussed in this paper: Automated feature extraction research and computer-assisted photo interpretation research. The discussion of automated information extraction indicates present day capabilities of automated systems, problems facing automated information extraction, and directions which basic research must take to achieve automated "smart analysis systems" in the distant future. The discussion of computer-assisted photo interpretation will describe the research system now being developed and experiments for research which is expected to have value in the near future for increasing the quality and efficiency of the total information extraction processes.

INTRODUCTION

The research and development program of the U. S. Army Engineer Topographic Laboratories (USAETL) contains a large number of efforts involving image information extraction. This attests to the wide variety of problems, the diverse nature of potential solutions, and perhaps most important, to the real and urgent need for improved information sources and the ever increasing requirements for better and more timely information. Presently, and with few exceptions, the photo interpreter represents the only proven means for information extraction from aerial imagery in a production environment. The interpretation tasks are labor intensive, time consuming, and often require a high level of expertise. For many organizations in the government, the improvement of acquisition systems and the need for rapid data extraction has led to research and development seeking new and improved methods and systems for extracting information from aerial imagery.

USAETL is conducting research at several levels in the extraction of natural and cultural data from aerial imagery. These levels range from assisting the operational photo interpreter with his present day problem solving and data manipulation tasks to basic research for automated pattern recognition systems of the future. Between these extremes USAETL is developing a large interactive digital image processing research facility

(DIA) having the capabilities of performing a wide range of functions of potential value to an image interpreter. Grey scale manipulation, geometric warping, scrolling, overlaying graphics, stereo mensuration, and anaglyphic stereo presentation are representative functions. Other examples of research activities at USAETL address image information extraction and presentation related to manual methods and techniques for the expert photo interpreter interested in soil, rock, vegetative and cultural patterns; Landsat data analysis techniques for small scale terrain material distribution studies; and special purpose thematic mapping for Military Geographic Information applications.

This short paper can not begin to do justice to the USAETL research in for information extraction from aerial imagery. Therefore, two selected research approaches will be discussed which represent one view of the wide range of the USAETL research. The first approach will deal with automated extraction of information from aerial photography in the distant future. This overview will be presented to acquaint the reader with the capabilities of present day automated systems, the problems facing automated information extraction, and the directions which basic research must take to attain "smart analysis systems." The second approach to be reviewed deals with computer-assisted photo interpretation research system employing today's technology to assist the human in his decision-making and data manipulation processes. This research is expected to have significant value in the near future for increasing quality and efficiency of the total information extraction processes.

RESEARCH FOR AUTOMATED INFORMATION EXTRACTION

An ultimate goal for an automatic aerial image information extraction system could be a desk-sized system containing a drawer into which a roll of aerial imagery is dropped, a few buttons pushed, and in a few seconds the desired information appears. Enormous amounts of money have been spent to develop automated systems with far less ambitious goals. From this we have learned that total automation is an unrealistic goal. More realistically, partial automation can be applied to the more mundane and repetitive problems where solutions are relatively well defined. Though this may seem to be a retraction from the desired purpose and scope of automation, it does historically place automation in an achievable context.

The lack of great automation successes should not imply that we are wasting research money in this direction, but rather that the direction must be more sharply focused. In this section capabilities of present day semi-automated systems will be outlined and the major problems facing automation will be indicated. The section will close with a brief discussion of research directions leading towards "smart" systems for the future.

Present Day Systems

The key to successful automation is to ferret out the simple, but im-

portant, tasks amenable to automated solutions. In some cases this can only be achieved by decomposing difficult tasks into simpler sub-tasks that lend themselves to clearer definition and have sufficient constraints in terms of available or achievable capabilities. Additionally, constraints may be added to yield a less general solution but render the problem tractable. A vivid example of adding constraints to a pattern recognition problem is seen in optical character recognition systems of today where well formed (i.e., size, shape, position, etc.) alphanumeric symbols can be recognized but free hand writing or back-of-the-letter printing is not within the capabilities of automatic reading systems.

An example of automating a simple but important task with aerial imagery involves the cloud screening system being developed by USAETL for the Defense Mapping Agency. In terms of pattern recognition from aerial imagery there perhaps could not be a simpler problem than detecting clouds or no clouds. In the mapping and intelligence communities cloud screening is an important problem because clouds obscur the landscape and their recognition and delineation from the aerial images is usually a simple but labor intensive manual task. Research at USAETL indicated that clouds could be detected with about 98% accuracy (Ref. 1), and a large format optical screening system is being assembled under contract to potentially allow screening rates of about 25 frames per minute in a production environment with about 1600 samples per frame. This same research capability has indicated potentials for automatic analysis for image information content screening and ocean wave analysis, (Ref. 2).

Certainly there are other limited successes in automated information extraction from aerial imagery; notably with the use of Landsat images. In all cases, however, these must be considered special purpose, semi-automated capabilities.

Difficulties Facing Automated Pattern Recognition

It is instructive to briefly mention the major difficulties facing automated pattern recognition from aerial imagery. The prime reason for the limited success to date concerns the variability of natural and cultural terrain features. If every feature class had a unique signature or fingerprint the task might be tractable, but this is not the case, at least in a simple sense. A second prime reason for difficulty concerns the environment and its relation to the terrain features and the images. For example, seasonal changes in vegetation and crops, seasonal and diurnal changes in solar illumination, and the effects of rain, snow, fog, haze, and smoke, all tend to change aerial images in a temporal sense. The aerial sensors provide added variability for in most cases the images are acquired for the purposes of qualitative analysis by interpreters rather than for quantitative analysis by machines. Today's sensors swamp us with data due to higher resolution and more rapid acquisition capabilities, but rarely do we have the luxury of working with images from sensors which best suit the problem. For example, black and white panchromatic photography

is most commonly available, and we know that this image type compresses the visual electromagnetic spectrum (from which we commonly see colors) into a limited number of grey tones. Images obtained at different scales and formats add additional variability to the analysis problem.

Another prime reason for our limited success in automating information extraction from aerial imagery involves our present state of analysis capabilities. Consider the statistical approaches wherein bean counting algorithms classify a pixel by brute force as wheat or water or whatever by the numbers which represent grey tone or multispectally sensed data. Most algorithms consider the numbers from each pixel only with respect to a statistical population as though they were drawn from a hat; each pixel is classified in turn from start to finish in a global fashion without any apriori information of physical value and without considering the environment, etc. This characterization of statistical pattern recognition is perhaps unfair, however we can say, without bias, that the present state of our analysis software is very unsophisticated.

Toward Smart Systems

Today's research is expected to provide potential solutions for problems of the future. This generalization pertains also to the above listed difficulties facing automated information extraction from aerial imagery. The author believes this research should be directed toward the development of "smart" systems. Here "smart" is loosely defined as some measure of decision quality usually attributed to humans but not to machines. In essence, this is the definition of artificial intelligence and several organizations, mostly at the university level, are conducting basic research in pursuit of artificial intelligence methods and techniques leading to smart systems of the future (Ref. 3). The Defense Advanced Research Projects Agency (DARPA) is sponsoring "Image Understanding" basic research in a number of these organizations. Under a separate memo of understanding with the Defense Mapping Agency, DARPA will have a prototype interactive workstation available for testing with 1983 that will incorporate artificial intelligence concepts for automatically extracting image information related to selected tasks which are yet to be defined.

The central concept of the image understanding relates to knowledge-based analysis wherein rule-based inference techniques enable expert judgemental knowledge about a specific problem domain to be represented as a collection of discrete rules (Ref. 4). Each rule states that if certain premises are known, then certain conclusions can be inferred. Interactive rule-based analysis has been used for diagnosing bacterial infections (Ref. 5) and pertinent computer-aided consultant research is being conducted by Stanford University and Stanford Research Institute (Ref. 6). It is believed that the development of knowledge-based image analysis will determine the generality and applicability of automated pattern recognition to complex tasks in the future.

Now that the concept of a smart system has been loosely defined, the difficulties facing automated pattern recognition, mentioned above, can be reviewed in the smart system context. For example, the variability of natural and cultural terrain features and the temporal environmental variations were indicated to present the major difficulties impeding present day automated image analysis techniques.[1] Given the tools associated with a smart system the general rules of nature for a given geographic area can be encoded as rules for a knowledge-based system. Thus, our pattern recognition system can begin to use knowledge from geology, physiography, ecology, meterology, etc. as a base and specific information of the time and place of imaging to coordinate the image with the knowledge base. Likewise, the knowledge base can include rules for different sensors in a manner which would normalize selected types of sensor variations. The difficulties associated with image scale and format can be handled in a similar manner. And perhaps the greatest benefit of smart image analysis systems will be most evident in upgrading the state of our image analysis capabilities from brute force statistical approaches to analysis techniques based on logic. Statistical algorithms will be applicable in smart systems, but as low level classification techniques selected and controlled by logic structures.

Smart systems will allow us to integrate our knowledge of the real world area under study. Digital cartographic data bases are expected to play key roles because for large areas of the earth's surface we will have knowledge of where major patterns of vegetation, water, roads, bridges, etc. are located.[2] In addition, terrain elevation data will be available *for analysis of landscape configurations.* Suppose we were interested in locating all structures associated with flood plains of a given river system. With knowledge data base which includes rules that associate "flood plains" with certain terrain configurations and the occurrence of "rivers" and "streams", and structures with access roads, etc., and if the imagery is coordinated with the digital cartographic data base, it would seem that the recognition and analysis tasks would be much more efficient than those afforded by present day techniques.

It must be emphasized that we have been discussing smart systems which we hope will evolve in the distant future from present and future basic research efforts. Now let us turn to research for extracting information from aerial imagery which could help us in the very near future.

COMPUTER-ASSISTED PHOTO INTERPRETATION RESEARCH

Since manual photo interpretation presently provides the only reliable operational capability for extracting a wide range of information from aerial imagery, it is essential to provide the interpreter with the facilities that will make him more efficient in his total work effort. Considerable attention has been given to the development of quality stereoscopic optical viewing systems for the photo interpreter but little attention has been devoted to the development of procedures and equipment to help the in-

terpreter extract, record, and manage information directly from the stereoscopic imagery. This total work effort not only deals with the process of annotating stereophoto overlays with symbols and lines indicating classifications and areal extents of terrain features pertinent to the problem at hand, but additionally to processes such as selection imagery for the study, retrieving available collateral information from the files related to the problem at hand and the area under study, and formating the output data into a product ready for distribution. USAETL is presently addressing this problem area and will have a research test-bed system in operation by March 1980 (Ref. 7).

Our basic objective is investigate new and innovative computer-assisted approaches to a wide range of present day operational photo interpretation and data processing applications. An initial computer-assisted photo interpretation research (CAPIR) system has been defined and is being procurred and assembled from state-of-the-technology components. It will basically provide a digital data encoding and management system for the photo interpreter to accomplish the total work effort. The photo interpreter will provide the difficult-to-automate capabilities for the decision-making and control function selection. Representative experiments have been outlined to demonstrate applications and cost effective benefits which will indicate an evolution of enhanced system capabilities and point to directions of future research. The system will now be described and this will be followed by a short discussion of the planned application tests.

CAPIR System

Design of the CAPIR system was based on the prerequisite that all components were off-the-shelf, so to speak. Two recent developments have profoundly influenced the nature of the system: The first has been the evolution of the analytical point positioning system (APPS) family of stereoscopic instrumentation which has led to a low-cost, commercial analytical plotter, and the second was the Wetlands Analytical Mapping System (WAMS) which has demonstrated the potential for on-line stereoscopic digitization of aerial photography to create and manage digital geographic data bases (Ref. 7).

The APPS-I prototype instrument was fabricated at USAETL and tested in 1972 as a simple, field-deployable point positioning system that integrated a Zeiss Stereotope, Bendix Datagrid, and a Hewlett-Packard 9810A calculator to operate on a data base of annotated stereo aerial photographs with predetermined camera parameters and control point coordinates (Ref. 8). In operation, two photos of a stereo pair are mounted on the instrument stages, control points are measured for system initialization and verification, then X, Y, Z coordinates for any number of points in the stereomodel are computed after centering on the point of interest and manually clearing x and y parallax. APPS-III is a non-ruggedized commercial version of the APPS that was developed under internal funding by IDEAS,

Inc. and used by Autometric, Inc. as a stereo digitizer in the WAMS for the U. S. Fish and Wildlife Service. It uses a Bausch and Lomb Zoom 240 Stereoscope and is interfaced to a Hewlett-Packard minicomputer. The APPS-IV is a commercial, medium-accuracy (RMS errors of less than 10 micrometers) analytical plotter announced by Autometric, Inc. in late 1978 (Ref. 9). It utilizes a minicomputer, the Bausch and Lomb Stereo Zoom Transfer, and several microprocessors in a compact desk-sized workstation. An option provides servocontrolled photo stages which maintains the stereomodel as stages are slewed in x and y directions in the field of a stationary cursor. Thus, the APPS-IV permits convenient stereo digitization in ground coordinates of point, line, or areal features.

WAMS was developed by Autometric, Inc. for the National Wetlands Inventory Project, U. S. Fish and Wildlife Service, to provide a computer-based system to delineate, classify, and inventory the wetlands of the United States (Ref. 10). It utilized an APPS-III to create a digital data base and has a software system with three distict on-line capabilities: aerotriangulation of source imagery; digitization for data base creation; and editing and data base management functions.

The CAPIR is built on the foundation of the WAMS software and the APPS-IV computer-interfaced stereoscope, then systematically augmented in hardware, software, and firmware to provide additional capabilities. As shown in Figure 1 and Table I, the CAPIR system is composed of five subsystems. The stereoscopic workstation provides the interpreter with a friendly man/machine interface and consists of the basic APPS-IV analytical plotter with servoed photo stages; internal firmware to allow on-line extraction of terrain elevation data by profiling; graphic superposition, wherein computer-generated graphics are optically superimposed in the stereomodel; and a CRT terminal. The monoscopic workstation subsystem supports digitization from map sheets and orthographic source materials for aerotriangulation and data base entry. The digital image workstation is designed to support future research in semi-automatic pattern recognition with the goal of developing techniques to permit the gradual transfer of selected decision-making responsibilities from the interpreter to the computer. This subsystem consists of an image sampler, an image display, and a CRT terminal. The system minicomputer and software subsystems complete the initial configuration.

CAPIR Application Experiments

Six experimental areas have been initially identified by elements of USAETL for research efforts. These are listed in Table II with the proposed research tasks and will be briefly discussed.

The objective of the point positioning and mensuration experiments is to develop improved photo interpretation methods for point positioning and stereo mensuration from metric and non-metric aerial imagery of different scales and formats for a selected set of measurement applications.

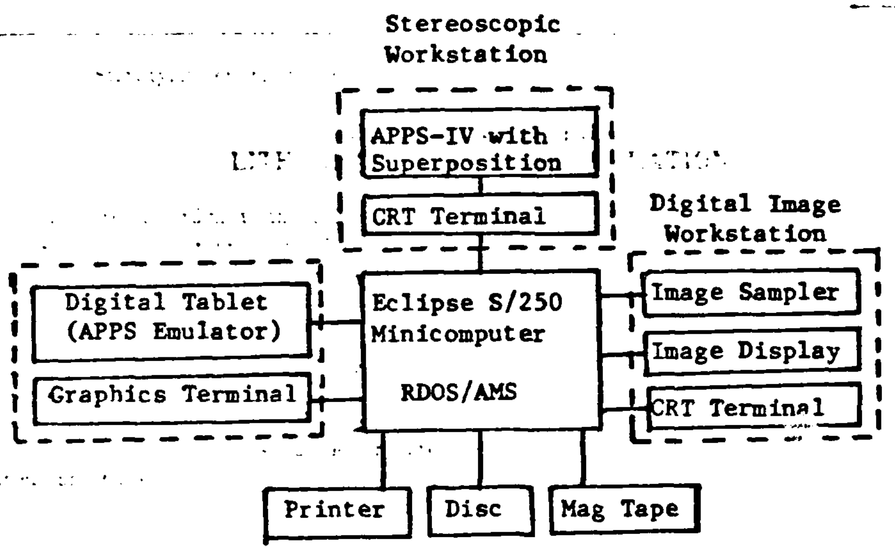

Figure 1. Computer-Assisted Photo Interpretation Research (CAPIR) Facility

The objective of the geographic information systems experiments is to demonstrate procedures for the creation of digital geographic data bases and develop computer graphics superposition with the stereomodel to permit validation, editing, updating, and intensification of derived data bases. Interactive spatial analysis of derived geographic data will provide optional display of synthesized products within the stereomodel.

The multi-source data fusion experiments have the general objective of investigating analysis and integration of data from dissimilar imagery and collateral sources through exploitation of common ground coordinate systems for superposition of data base information in the stereomodel.

Studies for elevation data extraction with the CAPIR system will evaluate concepts for generation, inspection, and editing of digital elevation data to support photogrammetric data production and terrain analysis.

Knowledge-based programming experiments will investigate the use of the computer to aid the photo interpreter's decision-making processes and will collect data to support knowledge-based terrain analysis basic research.

The objective of the semi-automated pattern recognition experiments is to conduct research in which the photo interpreter initializes a pattern recognition problem, invokes and evaluates the performance of selected automated classification procedures. Computer compatible tapes from the Recording Optical Spectrum Analysis system, when integrated with CAPIR image data, will simulate use of automated prescreening data to aid the interpreter.

TABLE I. CAPIR System Components

A. STEREOSCOPIC WORKSTATION

1. APPS-IV Analytical Plotter
2. Profiling firmware
3. Graphic superposition
4. CRT terminal

B. MONOSCOPIC WORKSTATION

1. Digital tablet (36" x 48" backlighted)
2. APPS-IV emulator for tablet
3. Graphics terminal

C. DIGITAL IMAGE WORKSTATION

1. Solid-state image sampling camera
2. Video processor with color monitor
3. CRT terminal

D. SYSTEM MINICOMPUTER AND PERIPHERALS

1. Data General Eclipse minicomputer with array processor
2. 20 Mbyte disc drive (interchangeable 10 Mbyte cartridge)
3. Magnetic tape drive (9 track, 800 bpi)
4. Character printer (180 characters/second)

E. SYSTEM SOFTWARE

1. Operating system: Data General RDOS
2. Principle programming language: FORTRAN V
3. WAMS software
4. Scientific subroutine library

TABLE II. Initial CAPIR Experiments

1. POINT POSITIONING AND MENSURATION

a. Absolute positioning accuracy
b. Direct mensuration of terrain features
c. Quantification of vegetation parameters
d. Computer-driven search and measurement of vertical obstractions
e. Definition of parameters to establish an urban rubble model.

2. GEOGRAPHIC INFORMATION SYSTEMS

a. Digital geographic data base operations
b. Generation synthesized terrain data products

TABLE II. Initial CAPIR Experiments cont'd

c. Estimation of forest parameters from small-scale imagery.

3. MULTI-SOURCE DATA FUSION

a. Use of multidate, multiscale imagery study of vegetation
b. Intelligence fusion of collateral data in the stereomodel.

4. ELEVATION DATA EXTRACTION

a. Production of digital terrain matrices
b. Intervisibility models
c. Terrain profiling in support of terrain analysis.

5. KNOWLEDGE-BASED PROGRAMMING

a. Support for knowledge-based terrain analysis research
b. Vertical obstruction pattern recognition
c. Voice recognition and voice synthesis.

6. SEMI-AUTOMATED PATTERN RECOGNITION

a. On-line sampling sensor and selected classification algorithms
b. Joint CAPIR/ROSA experiments.

PROGNOSIS

Information extraction from aerial imagery is a many-faceted problem area lacking a unique solution. In this environment, the photo interpreter continues to provide the only viable general purpose capability and yet for many reasons this is not an acceptable solution for either current or future demands. Presently, automation can serve in assisting roles where individual subproblems have been partitioned into well-defined tasks. To think of general purpose automation for information extraction from aerial imagery is fool hearty at this time because the proper foundation has not been prepared. Instead, the rationale for interactive systems that retain the human control and decision-making functions will present valid research objectives in the coming years. We can apply existing technologies initially to assist the photo interpreter in his total set of information extraction processes by preparing the data for decision-making and managing the information after the decision process. Where subproblems are better defined the machine can suggest solutions which require tuning by the interpreter. Addition of these capabilities in a plausible and pragmatic manner will lead to the evolution of useful systems as well as approaches toward the development of smart operational systems.

Current with the bottom-ups approach to development of computer-assisted capabilities, we must develop top-down means for organizing and

managing knowledge applicable to our problem areas. As rule-based decision-making matures, individual elements of the control and classification decisions can be accomplished by machine. Automation of these functions is dependent upon definition of interpreter logic in manner which the machine can trace or search for tractable solutions.

We should expect that highly automated systems for information extraction from aerial imagery will be a part of our production capabilities in the future if the proper research is provided as a foundation. Now, however, we must be content with assisting the interpreter in his domain while evolving to ever-improved capabilities. USAETL will continue to conduct research in these and other areas leading to smart interpreters, smart systems, and better means for extracting information from aerial imagery.

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